STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMENT
P.O. BOX 621
HONOLULU, HAWAII 96809

STAFF SUBMITTAL

for the meeting of the
COMMISSION ON WATER RESOURCE MANAGEMENT

February 17, 2010
Honolulu, Hawaii

Request to Authorize the Chairperson to Modify an Existing Planning Assistance to States Agreement with the U.S. Army Corps of Engineers for the Update of the *Rainfall Atlas of Hawaii*

SUMMARY OF REQUEST

Staff is requesting that the Commission authorize the Chairperson to modify an existing cost sharing agreement with the U.S. Army Corps of Engineers (USACE) to update the *Rainfall Atlas of Hawaii* and to authorize additional funding, subject to the availability of funds. The purpose of this modification is to expand the scope of work, under this agreement, to include investigation of historical rainfall trends and possible future changes in extreme rainfall events in Hawaii as global warming affects the regional climate.

BACKGROUND

In 2008, the Commission entered into a Planning Assistance to States agreement (Exhibit 1) with the USACE to update the *Rainfall Atlas of Hawaii*. Dr. Thomas Giambelluca, Professor, Geography Department, University of Hawaii at Manoa, was selected as the principal investigator. This project is currently underway and is expected to be completed by May 31, 2011. Commission cost share for this work is $177,510, which was matched with USACE funding.

The Energy and Water Development and Related Agencies Appropriations Act, 2010 (Public Law 111-90) appropriates $100,000 for State of Hawaii Rainfall Analysis under the USACE Planning Assistance to States (PAS) program. The Commission was approached to be the local sponsor for this appropriation, as this would be a natural expansion of the *Rainfall Atlas of Hawaii* update. Under PAS, there is a 1:1 cost share requirement.

Global climate change may have profound impacts to Hawaii's fresh water resources. Recent studies show declining rainfall and stream flow trends in Hawaii; however, the causes of these trends are unclear. Scientists hypothesize that climate change would produce more extreme weather events (e.g., more intense floods and prolonged droughts). Warmer air temperatures would cause increased evaporation and higher water demands in many sectors of the population. There are many uncertainties about how Hawaii's fresh water supplies will be affected and resource managers can no longer plan for the future assuming that Hawaii's climate will remain unchanged. Effective long-range planning can be achieved with a better understanding of how climate change impacts Hawaii's aquifers and streams.

A key building block to understanding how Hawaii's water resources may be affected is to better understand how rainfall may be affected. Rainfall is the primary source of our water supplies, and changes in rainfall will affect our assessments of available water resources. Besides rainfall, evapotranspiration is another important factor that influences the amount of water available to support instream uses and aquifer sustainable yields. Climate change may considerably transform these factors and alter our current estimates of ground water and surface water availability.

Climate change impacts to Hawaii have not been thoroughly investigated. By studying possible future rainfall scenarios and other factors affecting water resources, the Commission can better manage the State's water resources. Estimating future rainfall is the first step to refining aquifer sustainable yield estimates and instream flow standards. Staff will use this and other related studies to develop a climate change knowledge base for enhancing water resource assessment and management in Hawaii.

AGREEMENT MODIFICATION

The Commission is currently in a Planning Assistance to States agreement with the U.S. Army Corps of Engineers. The purpose of the agreement is to update the *Rainfall Atlas of Hawaii.* The Commission provided $177,510 towards this project with USACE providing an equal amount of funding as required under provisions of Section 22 of the Water Resources Development Act of 1974, as amended.

Under the existing agreement, Dr. Giambelluca is utilizing historical rainfall data and other methods to refine rainfall maps for the State of Hawaii, which was last updated in 1986. Dr. Giambelluca is collaborating with researchers from several disciplines to get the most accurate estimates of annual and monthly rainfall based on the last 30 years of data.

Under the proposed agreement modification, the Commission would investigate historical rainfall trends and possible future changes in rainfall in Hawaii. Commission staff is working with the University of Hawaii on the details of expanding the current project scope to address climate change. A preliminary proposal from Dr. Giambelluca (Exhibit 2) includes the following objectives:

- Utilize newly developed rainfall data to assess historical trends and changes in spatial patterns in Hawaiian rainfall

- Establish relationships between extreme high-rainfall events and large scale weather patterns to assess whether model simulations suggest any changes in the frequency of these extreme high-rainfall events

- Establish relationships between extreme low-rainfall periods and large scale weather patterns to assess whether model simulations suggest any changes in the frequency of these extreme low-rainfall events.

The proposal also describes methods for achieving these objectives, and is related to another research project underway by Dr. Giambelluca: *High Resolution Climate Data Sets for Climate Diagnostics and Climate Change Detection in Hawaii,* which is funded by a grant from the National Oceanographic and Atmospheric Administration (NOAA).

FUNDING

Under PAS program provisions, USACE funding requires a 1:1 cost share. Besides direct funding, cost share can include in-kind services for work done towards the completion of the PAS agreement objectives. USACE will allow the NOAA cost for Dr. Giambelluca's project *High Resolution Climate Data Sets for Climate Diagnostics and Climate Change Detection in Hawaii* to be counted toward the cost share (in-kind services) of this proposed Rainfall Climate Change Project. Staff is proposing that the remainder of the cost share be provided by the Commission. The table below describes the proposed funding arrangement.

Funding Agency	Federal funding	State funding	Other cost share	Project funding
U.S. Army Corps of Engineers	$100,000			
Commission		$31,000		$131,000 (for new work)
University of Hawaii			$69,000	$69,000 (in-kind services)
Totals	$100,000	$31,000	$69,000	$200,000

Total project cost would be $200,000. Funding available for new work is $131,000. Commission would provide $31,000 in State funds and USACE would provide $100,000 in Federal funds. The University of Hawaii will use its NOAA grant of $69,000 as in-kind services for the remaining cost share.

Commission staff will work closely with USACE and Dr. Giambelluca to develop a final scope of services, fee proposal, and completion schedule, which will be made part of the agreement modification subject to the Chairperson's approval. This project is expected to be completed in 18 to 24 months from notice to proceed.

RECOMMENDATIONS

1. Staff recommends that the Commission authorize the Chairperson to modify the existing Planning Assistance to States agreement to update the *Rainfall Atlas of Hawaii* for the purpose of investigating historical rainfall trends and possible future changes in extreme rainfall events in Hawaii, and to provide cost share funding for this work not to exceed $31,000 from Commission general or special funds, or a combination of both, subject to the availability of funds, for this additional investigation as described in Exhibit 2.

2. Staff also recommends that the Commission authorize the Chairperson to further amend or modify this agreement provided that such amendment or modification does not include any additional funding.

The terms of this agreement will be subject to the approval of the Chairperson and the Department's Deputy Attorney General.

Respectfully submitted,

KEN C. KAWAHARA, P.E.
Deputy Director

Exhibits:
1. Planning Assistance to States Agreement
2. Investigation of Historical Rainfall Trends and Possible Future Changes in the Frequency of Extreme High and Low Rainfall in Hawaii

APPROVED FOR SUBMITTAL:

LAURA H. THIELEN

PLANNING ASSISTANCE TO STATES AGREEMENT

BETWEEN

THE DEPARTMENT OF THE ARMY

AND

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
COMMISION ON WATER RESOURCE MANAGEMENT

FOR THE

RAINFALL ATLAS OF HAWAII
SECTION 22 STUDY

THIS AGREEMENT is entered into this 26th day, of June, 2008, by and between the Department of the Army (hereinafter the "Government"), represented by the District Engineer executing this Agreement, and the State of Hawaii, Department of Land and Natural Resources (DLNR) (hereinafter the "Sponsor"),

WITNESSETH, that

WHEREAS, Section 22 of the Water Resources Development Act (WRDA) of 1974 (Public Law 93-251), as amended, authorizes the Secretary of the Army, acting through the Chief of Engineers, to cooperate with any State, as therein defined, in the preparation of comprehensive plans for the development, utilization and conservation of water and related resources of drainage basins, watersheds, or ecosystems located within the boundaries of such State and to submit to Congress reports and recommendation with respect to appropriate Federal participation in carrying out such plans;

WHEREAS, Section 319 of the Water Resources Development Act of 1990 (Public Law 101-640) authorizes the Secretary of the Army to collect from non-Federal entities fees for the purpose of recovering 50 percent of the cost of the program established by Section 22 of the 1974 WRDA;

WHEREAS, Section 208(1) of WRDA 1992, Public Law 102-580 (codified at 42 U.S.C. Section 1962d-16(b)(2)), authorizes the Sponsor to contribute up to on-half (1/2) of the non-Federal contribution for preparation of the Scope of Work incorporated into this Agreement by the provision of services, materials, supplies or other in-kind-services necessary to prepare the Scope of Work.

WHEREAS, the Sponsor has reviewed the State's comprehensive water plans and identified the need for planning assistance as described in the Scope of Work incorporated into this agreement; and

WHEREAS, State general fund money in the amount of one hundred thirty eight thousand dollars ($138,000) and State special fund money is the amount of thirty nine

EXHIBIT 1

thousand five hundred ten dollars ($39,510) are available to fund this Agreement pursuant to Act 213, Session Laws of Hawaii, 2007, item D.5.

WHEREAS, the Sponsor has the authority and capability to furnish the cooperation hereinafter set forth and is willing to participate in the study cost-sharing and financing in accordance with the terms of this Agreement;

NOW THEREFORE, the parties agree as follows:

ARTICLE I - DEFINITIONS

For the purposes of this Agreement:

A. The term "Study Costs" shall mean all disbursements by the Government pursuant to this Agreement, from Federal appropriations or from funds made available to the Government by the Sponsor and all negotiated costs of work performed by the Sponsor pursuant to this Agreement. Study Costs shall include, but not be limited to: labor charges; direct costs; overhead expenses; supervision and administration costs; the costs of participation in Study Management and Coordination in accordance with Article IV of this Agreement; the costs of contracts with third parties, including termination or suspension charges; and any termination or suspension costs (ordinarily defined as those costs necessary to terminate ongoing contracts or obligations and to properly safeguard the work already accomplished) associated with this Agreement.

B. The term "estimated Study Costs" shall mean the estimated cost of performing the Study as of the effective date of this Agreement, as specified in Article III.A. of this Agreement.

C. The term "study period" shall mean the time period for conducting the Study, commencing with the release to the U.S. Army Corps of Engineers, Honolulu District of initial Federal funds following the execution of this Agreement and ending when the Honolulu District provides the planning report to the Sponsor.

D. The terms "SOW" and "Scope of Work" shall mean the Preliminary Proposal to Revise the Rainfall Atlas of Hawai`i, which is attached to this Agreement and which shall not be considered binding on either party and is subject to change by the Government, in consultation with and approval by the Sponsor.

E. The term "fiscal year" shall mean one fiscal year of the Government. The Government fiscal year begins on October 1 and ends on September 30.

F. The term "negotiated costs" shall mean the costs of in-kind services to be provided by the Sponsor in accordance with the SOW.

ARTICLE II - OBLIGATIONS OF PARTIES

A. Subject to the availability of funds appropriated by the Congress of the United States (Congress), the Government, using funds and in-kind services provided by the Sponsor and Congressionally appropriated funds, shall expeditiously prosecute and complete the Study, in accordance with the provisions of this Agreement and Federal laws, regulations, and policies.

B. In accordance with this Article and Article III. of this Agreement, and subject to appropriation by the Hawaii State Legislature and allocation by the State executive budget process, the Sponsor shall contribute cash or in-kind services equal to fifty (50) percent of Study Costs. If agreeable to all parties, in-kind services may comprise fifty (50) percent of the Sponsor's contributions or twenty five (25) percent of Study Costs. The in-kind services to be provided by the Sponsor, the estimated negotiated costs for those services, and estimated schedule under which those services are to be prepared are specified in the Scope of Work. Negotiated costs shall be subject to an audit by the Government to determine reasonableness, allocability and allowability.

C. The Sponsor understands that the schedule of work may require the Sponsor to provide cash or in-kind services at a rate that may result in the Sponsor temporarily diverging from the obligations concerning cash and in-kind services specified in paragraph B. of this Article. Such temporary divergences shall be identified in the quarterly reports provided for in Article III.A. of this Agreement and shall not alter the obligations concerning payment specified in paragraph B. of this Article or the obligations concerning payment specified in Article III of this Agreement.

D. If, upon the award of any contract or the performance of any in-house work for the Study by the Government, cumulative financial obligations of the Government and the Sponsor would exceed $355,020, the Government and the Sponsor agree to defer award of that and all subsequent contracts, and performance of that and all subsequent in-house work, for the Study until the Government and the Sponsor agree to proceed. Should the Government and the Sponsor require time to arrive at a decision, the Agreement will be suspended in accordance with Article X., for a period of not to exceed six months. In the event the Government and the Sponsor have not reached an agreement to proceed by the end of their 6-month period, the Agreement may be subject to termination in accordance with Article X.

E. No Federal funds may be expended or obligated by the Sponsor to meet the Sponsor's share of Study costs under this Agreement unless the expenditure or obligation of such funds is expressly authorized by statute for such purposes and the Federal granting agency verifies in writing that the expenditure of such funds is expressly authorized by statute.

F. The award and management of any contract with a third party in furtherance of this Agreement which obligates Federal appropriations shall be exclusively within the control of the Government. The award and management of any contract by the Sponsor with a third party in furtherance of the Agreement which obligates funds of the Sponsor and does not obligate Federal appropriations shall be exclusively within the control of the Sponsor, but shall be subject to applicable Federal laws and regulations.

G. Notwithstanding any provision of this Agreement, this Agreement and the Government's obligations hereunder shall not be effective and will not commence until Federal funds have been appropriated and allocated to the District Engineer, U.S. Army Corps of Engineers Honolulu District for the implementation of this study. In the event that Federal funds are allocated to the District Engineer for this study after the date that the parties hereto execute this Agreement, the effective date of this Agreement shall be the date that funding approval is provided to the District Engineer.

H. In the event that any one or more of the provisions of this Agreement is found to be invalid, illegal, or unenforceable, by a court of competent jurisdiction, the validity of the remaining provisions shall not in any way be affected or impaired and shall continue in effect until the Agreement is completed.

ARTICLE III - METHOD OF PAYMENT

A. The Government shall maintain current records of contributions provided by the parties, current projections of Study Costs, current projections of each party's share of Study Costs. At least quarterly, the Government shall provide the Sponsor a report setting forth this information. As of the effective date of this Agreement, estimated Study Costs are $355,020 and the Sponsor's share of estimated Study Costs is $177,510. In order to meet the Sponsor's cash payment requirements for its share of estimated Study Costs, the Sponsor must provide a cash contribution currently estimated to be $177,510. The dollar amounts set forth in this Article are based upon the Government's best estimates, which reflect the scope of the study described in the SOW, projected costs, price-level changes, and anticipated inflation. Such cost estimates are subject to adjustment by the Government and are not to be construed as the total financial responsibilities of the Government and the Sponsor.

B. The Sponsor shall provide its cash contribution required under Article II.B. of this Agreement in accordance with the following provisions:

1. No later than 30 days prior to the scheduled date for the Government's issuance of the solicitation for the first contract for the Study or for the Government's anticipated first significant in-house expenditure for the Study, the Government shall notify the Sponsor in writing of the funds the Government determines to be required from the Sponsor to meet its share of Study Costs. No later than 15 days thereafter, the Sponsor shall provide the Government the full amount of the required funds by delivering a check payable to "FAO, USAED, Honolulu District" to the District Engineer or an Electronic Funds Transfer in accordance with procedures established by the Government.

2. The Government shall draw from the funds provided by the Sponsor such sums as the Government deems necessary to cover the Sponsor's share of contractual and in-house financial obligations attributable to the Study as they are incurred.

3. In the event the Government determines that the Sponsor must provide additional funds to meet its share of Study Costs, the Government shall so notify the Sponsor in writing. No later than 60 days after receipt of such notice, the Sponsor shall provide the Government with a check or an Electronic Funds Transfer for the full amount of the additional required funds.

C. Within 90 days after the conclusion of the Study Period or termination of this Agreement, the Government shall conduct a final accounting of Study Costs, including disbursements by the Government of Federal funds, cash contributions by the Sponsor and credits for the negotiated costs of the Sponsor's in-kind services, and shall furnish the Sponsor with the results of this accounting. Within 30 days thereafter, the Government, subject to the availability of funds, shall reimburse the Sponsor for the excess, if any, of cash contributions and credits given over its required share of Study Costs, or the Sponsor shall provide the Government any cash contributions required for the Sponsor to meet its required

share of Study Costs.

ARTICLE IV - STUDY MANAGEMENT AND COORDINATION

To provide for consistent and effective communication, the Government's Project Manager for the Study and the Sponsor's designated representative shall communicate regularly until the end of the Study Period.

ARTICLE V - DISPUTES

As a condition precedent to a party bringing any suit for breach of this Agreement, that party must first notify the other party in writing of the nature of the purported breach and seek in good faith to resolve the dispute through negotiation. The existence of a dispute shall not excuse the parties from performance pursuant to this Agreement.

ARTICLE VI - MAINTENANCE OF RECORDS AND AUDIT

A. Within 60 days of the effective date of this Agreement, the Government and the Sponsor shall develop procedures for keeping books, records, documents, and other evidence pertaining to costs and expenses incurred pursuant to this Agreement. These procedures shall incorporate, and apply as appropriate, the standards for financial management systems set forth in the Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments at 32 C.F.R. Section 33.20. The Government and the Sponsor shall maintain such books, records, documents, and other evidence in accordance with these procedures and for a minimum of three years after the period of design and resolution of all relevant claims arising therefrom. To the extent permitted under applicable Federal and State laws and regulations, the Government and the Sponsor shall each allow the other to inspect such books, documents, records, and other evidence.

B. In accordance with 31 U.S.C. Section 7503, the Government may conduct audits in addition to any audit that the Sponsor is required to conduct under the Single Audit Act. Any such Government audits shall be conducted in accordance with Government Auditing Standards and the cost principles in OMB Circular No. A-87 and other applicable cost principles and regulations. The costs of Government audits shall be included in total Study Costs and cost shared in accordance with the provisions of this Agreement.

ARTICLE VII - RELATIONSHIP OF PARTIES

The Government and the Sponsor act in independent capacities in the performance of their respective rights and obligations under this Agreement, and neither is to be considered the officer, agent, or employee of the other.

ARTICLE VIII - OFFICIALS NOT TO BENEFIT

No member of or delegate to the Congress, nor any resident commissioner, shall be admitted to any share or part of this Agreement, or to any benefit that may arise therefrom.

ARTICLE IX - FEDERAL AND STATE LAWS

In the exercise of the Sponsor's rights and obligations under this Agreement, the Sponsor agrees to comply with all applicable Federal and State laws and regulations, including Section 601 of Title VI of the Civil Rights Act of 1964 (Public Law 88-352) and Department of Defense Directive 5500.11 issued pursuant thereto and published in 32 C.F.R. Part 195, as well as Army Regulations 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army."

ARTICLE X - TERMINATION OR SUSPENSION

A. This Agreement shall terminate at the conclusion of the Study Period, and neither the Government nor the Sponsor shall have any further obligations hereunder, except as provided in Article III.C.; provided, that prior to such time and upon 30 days written notice, either party may terminate or suspend this Agreement. In addition, the Government shall terminate this Agreement immediately upon the failure of the parties to extend the study under Article II.D. of the Agreement, or upon failure of the Sponsor to fulfill its obligation under Article III. of this Agreement. In the event that either party elects to terminate this Agreement, both parties shall conclude their activities relating to the Study and proceed to a final accounting in accordance with Article III.C. of this Agreement. Upon termination of this Agreement, all data and information generated as part of the Study shall be made available to both parties.

B. Any termination of this Agreement shall not relieve the parties of liability for any obligations previously incurred, including the costs of closing out or transferring any existing contracts.

ARTICLE XI – LIMITATION ON GOVNERNMENT EXPENDITURE

In accordance with Section 22 of WRDA 1974, as amended, Government financial participation in the cooperative preparation of comprehensive plans for development, utilization, and conservation of water and related resources pursuant to said authority shall be limited to the expenditure of not more than $500,000 in any one year in any one State.

IN WITNESS WHEREOF, the parties hereto shall have executed this Agreement upon the date it is signed by both the parties. It shall become effective pursuant to the provisions of Article II. G. of the Agreement.

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES

BY: _____ DATE: JUN 25 2008

for LAURA H. THIELEN
Chairperson

DEPARTMENT OF THE ARMY

BY: _____ DATE: 26 June 08

CHARLES H. KLINGE
Lieutenant Colonel, Corps of Engineers
District Engineer

APPROVED AS TO FORM:

_____ DATE: June 25, 2008

Deputy Attorney General
State of Hawaii

Attachment - Scope of Work, Budget Estimate

NON-FEDERAL SPONSOR'S
SELF-CERTIFICATION OF FINANCIAL CAPABILITY
FOR AGREEMENTS

I, Ken C. Kawahara, do hereby certify that I am the Deputy Director of the State of Hawaii, Department of Land and Natural Resources ("Non-Federal Sponsor"); that I am aware of the financial obligations of the Non-Federal Sponsor for the Rainfall Atlas of Hawaii, Section 22 Study; and that the Non-Federal Sponsor has the financial capability to satisfy the Non-Federal Sponsor's obligations under the Rainfall Atlas of Hawaii, Section 22 Study, Cost Sharing Agreement.

IN WITNESS WHEREOF, I have made and executed this certification this ____ day of JUN 25 2008, 20__.

BY: Ken C. Kawahara

TYPED NAME: Ken C. Kawahara

TITLE: Deputy Director

DATE: JUN 25 2008

Preliminary Proposal to Revise the Rainfall Atlas of Hawai'i

PI: Thomas Giambelluca, Geography, University of Hawai'i at Mānoa
Co-PI: Qi Chen, Geography University of Hawai'i at Mānoa
Collaborator: David Chen, Meteorology, University of Hawai'i at Mānoa
Collaborator: Kevin Kodama, National Weather Service, NOAA, Honolulu
Collaborator: Jonathan Price, Geography and Environmental Studies, UH Hilo
Collaborator: Thomas Schroeder, Meteorology, University of Hawai'i at Mānoa
Research Assistant: Michael Nullet, Geography, University of Hawai'i at Mānoa

Proposed Duration: 24 months

Introduction

The Hawaiian Islands have one of the most spatially-diverse rainfall patterns on earth. Island topography, persistent trade winds, thermal effects of the islands, and the presence of the trade-wind inversion interact to cause air to be lifted in distinct spatial patterns anchored to the topography. The resulting clouds and rainfall produced by this uplift lead to extreme gradients in mean monthly and annual rainfall in the islands. Knowledge of the mean rainfall patterns is critically important for a variety of resource management issues, including ground water and surface water development and protection, controlling and eradicating invasive species, protecting and restoring native ecosystems, and planning for the effects of global warming.

The Rainfall Atlas of Hawai'i (Giambelluca et al., 1986, herein referred to as Atlas86) was developed from rainfall observations at more than 2000 sites in Hawai'i, with means and medians adjusted to a common base period, and with isohyets drawn manually to represent spatial patterns. This method utilized all the available raingage data and used expert knowledge to "fill in the gaps". Despite the large number of raingage sites, large gaps existed then and still do today. These areas are generally remote, wet, forested areas, which are difficult to access for measurement. However, these areas are often among the most important in terms of water resources planning and management and ecological protection.

Atlas86, perhaps the most frequently cited scientific publication on Hawai'i's environment, is now more than 20 years old and in need of revision. While still the standard for water resource and ecological research and management, it is time to update and improve this important resource. We propose to develop a new digital Rainfall Atlas of Hawai'i including high-resolution maps of mean monthly and annual rainfall for all the major Hawaiian Islands. Rather than relying only on raingage data and expert knowledge, we propose to supplement those sources with other predictors, especially in gap areas, using a variety of innovative techniques. At each grid location, these various estimates and their uncertainties will be merged to produce the best estimate of the mean and uncertainty at that location.

Methods

Contemporary direct or indirect methods of rainfall estimation are subject to significant errors and uncertainty (Clark and Slater 2006). Rainfall information derived from raingages, radar or satellites may not individually be adequate to meet the detail required, for example, by hydrological models (Frezghi and Smithers 2007). Different techniques have been developed to merge rainfall information from different sources in order to obtain the "best" estimate of the "true" rainfall field using statistical models (e.g. Pegram and Clothier, 2001; Todini, 2001) or models based on the physical properties of a rain cell or cloud (Gupta and Waymire, 1993).

We propose to use some or all of the following list of rainfall estimation procedures, each producing estimates at some or all of the grid locations covering the state:

1. Updated raingage data, with statistics adjusted to a common base period; information available only at gage sites.

   A wealth of raingage data are available in Hawai'i. Raingages have been operated at roughly 2000 sites in Hawai'i at one time or another. These stations have been established at different times and have been operated for varying lengths of time. Because of interdecadal fluctuations in rainfall, normals from stations operated during different time periods may reflect temporal differences which give rise to spurious spatial patterns when used to map normal rainfall. In preparing maps for Atlas86, this problem was addressed using a form of multiple regression to adjust station normals to a common base period. We propose to use a similar approach to take advantage of raingage data measured in different eras, while minimizing error in the spatial pattern resulting from long-term rainfall fluctuations.

2. Raingage data interpolated to grid using topographic co-variables; information available at all grid locations; uncertainty greater in areas without gages.

   This approach has been used to develop mean rainfall maps for the U.S., including Hawaii, as part of the PRISM Project (Daly et al., 2008). We propose to use existing PRISM maps as one source of information on the spatial patterns of rainfall.

3. Mean radar rainfall estimates "calibrated" using gage data; estimate available in areas with good radar exposure.

   Approximately eight years of Level-3 WSR-88D radar rainfall data have been archived. These estimates have a resolution of 1 degree by 1.0 km (Tomlinson et al., 2006). The Level-3 data set is a derived product in which rainfall rates have been estimated from radar reflectivity measurements, using a statistical relation. Standard and tropical algorithms are used at different times in Hawai'i. We will composite all existing data to produce mean estimated rainfall patterns. The data

in polar coordinates for each radar unit, will be merged and mapped in Cartesian coordinates for comparison with other sources. The gridded values will be evaluated at raingage sites to determine the patterns of biases and uncertainty in the estimates. Based on this evaluation, estimates will adjusted where coverage is sufficient. In some areas, radar coverage will not be sufficient, and no estimates will be made.

4. Mean MM5 rainfall (Yang and Chen, 2008) estimates calibrated using gage data; estimates available at model resolution for whole state.

   High resolution daily experimental model forecasts over the entire state (9-km resolution), Hawai'i Island and Maui-Moloka'i-Lana'i Islands (3-km resolution), O'ahu (1.5-km resolution), and Kaua'i (1.5-km resolution) have been operational since 2003. Model runs are initialized from the global NCEP (National Centers for Environmental Prediction, Washington, DC) model output at 0000 UTC (1400 HST) each day and run for 36-hr high-resolution forecasts. The model forecast of hourly rainfall during 12-35 h will be used to represent the diurnal cycle of rainfall for each day. For this project, we will compile the model-simulated rainfall climatology for each individual island using the model output during January 1, 2004 to December 31, 2007. Annual and monthly high-resolution rainfall climatology for each island will be constructed with a 1.5-km resolution for Oahu and Kauai and a 3-km resolution for other islands consistent with model grids. The rainfall climatology will be interpolated to raingage locations and compared with observations statistically. The seasonal and spatial bias in model-simulated monthly rainfall will be investigated and used to adjust the model estimates and assess the pattern of uncertainty.

5. Rainfall estimates derived from vegetation distribution: estimates available mainly in relatively undisturbed mountain regions.

   Price et al. (2007) have used climate, substrate age, biogeographical regionalization, and patterns of human disturbance to map the patterns of vegetation in the islands. As part of that effort, moisture zones were defined, representing zones with similar water input (rainfall plus cloud water interception [CWI] or "fog drip") minus water use (evapotranspiration). We will transform the moisture zone map into a continuous moisture grid. By subtracting out estimated water use, a map of water input will be developed. This map will give the pattern of rainfall plus CWI derived from the known vegetation distribution. A remaining problem will be developing a method to estimate and remove the pattern of CWI from this map, which will be done based on recent field and modeling of the CWI distribution (Giambelluca et al., accepted). On the other hand, the independent estimate of CWI will be valuable in its own right as a source of information about this important hydrological variable (DeLay and Giambelluca, accepted).

To merge this information to generate gridded fields of rainfall, we will use a stochastic model that can combine information from the sources listed above. This method is modified from Clark and Slater (2006). It uses locally weighted regression, where topographic attributes are used as explanatory variables to estimate spatial variations in precipitation occurrence and precipitation amounts. Together estimates of precipitation occurrence, precipitation amounts, and the error in the amounts estimate define the conditional cumulative probability distribution function (cdf) of precipitation totals at each grid cell. Spatially coherent gridded ensembles are generated using grids of correlated random numbers to sample from fields of the sources listed. The rainfall estimation will be verified with cross-validation methods using rainfall gauge measurements.

Products

The project proposed here will result in the following products:

1. Digital maps of mean monthly and annual rainfall for the whole state (including all the major Hawaiian Islands) at a 250-m spatial resolution.
2. Digital maps of uncertainty in mean monthly and annual rainfall.
3. A report (in pdf format) describing the methods and results of the rainfall mapping procedure.
4. A web site (to be hosted on the Water Commission server) with links to report, map images, gridded rainfall data, tabular station information and data, and other relevant information.
5. One or more scientific papers, describing the methods and results of the study, will be submitted for publication in appropriate journals.

Report

The report will describe in detail the input data and procedures used to develop the revised rainfall maps, discuss the resulting patterns, identify areas where the estimates have changed significantly since the previous analysis, explain the patterns and sources of uncertain in the rainfall estimates, and discuss the implications of global climate change for rainfall patterns in Hawai'i.

Caveats

The successful conduct of the proposed research depends on the monthly rainfall data base for Hawai'i and the data base of climate station geographical coordinates and elevations, maintained by the Office of the State Climatologist, being made freely available. The budget does not cover the costs of gathering, checking, and digitizing monthly rainfall data. The project will test the use of innovative techniques to utilize all relevant information to determine the mean rainfall pattern. Some of these techniques may prove to be unsuitable for this purpose and therefore may not be included in the final product. The scope of the project is limited to development of digital maps (as GIS grids and digital images) of mean rainfall and an accompanying report (also in digital form).

References

Clark M. P. and A. G. Slater, 2006. Probabilistic quantitative precipitation estimation in complex terrain. *Journal of Hydrometeorology*, 7(1): 3-22.

Daly, C., Halbleib, M., Smith, J.I., Gibson, W.P., Doggett, M.K., Taylor, G.H., Curtis, J., and Pasteris, P.A., 2008. Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States. *International Journal of Climatology*, DOI: 10.1002/joc.1688.

DeLay, J.K., and Giambelluca, T.W. Accepted. History of cloud water interception research in Hawai'i. In J.O. Juvik, L.A. Bruijnzeel, F.N. Scatena, and P. Bubb (eds.) *Mountains in the Mist: Science for Conserving and Managing Tropical Montane Cloud Forests.*

Frezghi M.S., and J.C. Smithers, 2007. Merged rainfall fields for continuous simulation modeling. ASABE Annual International Meeting, Minneapolis, Minnesota, 17 - 20 June 2007.

Giambelluca, T.W., Nullet, M.A., and Schroeder, T.A. 1986. Hawaii Rainfall Atlas, Report R76, Hawai'i Division of Water and Land Development, Department of Land and Natural Resources, Honolulu. vi + 267 p.

Giambelluca, T.W., DeLay, J.K., Nullet, M.A., Scholl, M.A., and Gingerich, S.B. Accepted. Interpreting canopy water balance and fog screen observations: Separating cloud water from wind-blown rainfall at two contrasting forest sites in Hawai'i. In J.O. Juvik, L.A. Bruijnzeel, F.N. Scatena, and P. Bubb (eds.) *Mountains in the Mist: Science for Conserving and Managing Tropical Montane Cloud Forests.*

Gupta, V.K. and Waymire, E.C., 1993. A statistical analysis of mesoscale rainfall as a random cascade. *Journal of Applied Meteorology*, 32: 251-267.

Pegram, G.G..S and Clothier, A.N., 2001. Downscaling rainfields in space and time, using the string of beads models in causal mode. *Hydrology and Earth System Science*, 5, 175-186.

Price, J., Gon III, S.M. Jacobi, J.D., and Matsuwaki, D. 2007. Mapping Plant Species Ranges in the Hawaiian Islands: Developing a Methodology and Associated GIS layers. Hawai`i Cooperative Studies Unit Technical Report HCSU-000. University of Hawai'i at Hilo. 58 pp.

Todini, E., 2001. Bayesian conditioning of RADAR to rain gauges. *Hydrology and Earth System Science*, 5, 225-232.

Tomlinson, E., Kappel, B., Parzybok, T., and Rappolt, B. 2006. Use of NEXRAD weather radar data with storm precipitation analysis system (SPAS) to provide high spatial resolution hourly rainfall analyses for runoff model calibration and validation. Association of State Dam Safety Officials Annual Conference, Boston.

Yang, Y. and Chen Y., 2008. Effects of terrain heights and sizes on island-scale circulations and rainfall for the Island of Hawaii during HaRP. *Monthly Weather Review* 136(1): 120-146.

Project: Rainfall Atlas of Hawaii
Authority: Planning Assistance to States (Section 22, WRDA 1974)
Non-Federal Sponsor: State of Hawaii, Department of Land and Natural Resources (CWRM)

Work Task	Project Cost		
	Year -1	Year -2	Total
Task Order (Basic/Option)			
Myounghee Noh & Assoc. (Prime) 12.5%			$33,115
University of Hawaii (Sub)			$264,919
Sub Total			$298,034
USACE - Honolulu District			
Programs/Project Management (24 mos.)	$13,906	$9,280	$23,186
Financial Management (24 mos.)	$4,104	$2,736	$6,840
Task Order Pre-Award Prep (MATOC)	$2,580		$2,580
Task Order Award - Basic (Contracting)	$3,000		$3,000
Task Order Award - Option (Contracting)		$2,500	$2,500
Contract Administration (24 mos.)	$5,160	$5,160	$10,320
Technical Review (SOW/Draft Deliverables)	$2,140	$6,420	$8,560
Sub Total			$56,986
Total Project Cost			$355,020

Project Cost Share (50/50)	USACE	DLNR
	$177,510	$177,510

Research Proposal

Investigation of Historical Rainfall Trends and Possible Future Changes in the Frequency of Extreme High and Low Rainfall in Hawai'i

Thomas W. Giambelluca, Principal Investigator
Department of Geography, University of Hawai'i at Mānoa

12 December 2009

Introduction

Climate change is likely to have significant impacts on Hawai'i's water resources, agriculture, economy, and natural environment. While continuation of the warming seen in the past 100 years (Giambelluca et al. 2008) is a virtual certainty in Hawai'i, effects of global climate change on precipitation in Hawai'i are not well known. An analysis of historical trends in rainfall by Chu and Chen (2005) suggests a drying trend during the past 100 years, especially for the winter period. However, high interannual variability, associated in part with cyclical changes in oceanic and atmospheric states associated with the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), make determination of secular trends difficult. In addition, it is not known whether long-term changes have varied spatially. Assessment of the effects of natural year-to-year variability and examination of spatial variability has been hindered by the constantly changing distribution of the raingage network in Hawai'i. As stations are discontinued and new ones begin operating, spurious changes in spatial patterns and means can result, making the true patterns and trends difficult to discern.

Extreme high rainfall and extended periods of extreme low rainfall are of major importance in Hawai'i because of their effects on water supply, flooding, agriculture, and the natural environment. Globally, the proportion of total precipitation occurring during extreme high events is on the increase. In Hawai'i, rainfall in the upper decile has been shown to account for a large proportion of total rainfall and has a disproportionate influence on interannual rainfall variability. Droughts in Hawai'i appear to have been more frequent in recent decades. As water demand increases, extended dry periods have greater impacts on the economic wellbeing of the State. Global warming is certain to bring significant changes to Hawai'i's climate. However, the effects on rainfall are still uncertain. Timm and Diaz (2009) recently showed that winter rainfall may decline due to warming, but the results are somewhat equivocal because of poor agreement among models. Little is known about effects of climate change on extreme rainfall in Hawai'i. In the proposed study, we will investigate how rainfall extremes in Hawai'i are likely to change during this century as global warming affects the regional climate.

The objectives of the proposed project are given below.

1. Utilize newly developed serially-complete rainfall time series to estimate seasonal and annual spatial means for islands, regions, and the whole State, and use these

EXHIBIT 2

annual time series as a new method of assessing the historical trends and changes in spatial patterns in Hawai'i rainfall.

2. Establish statistical relationships between occurrences of extreme high rainfall at selected raingage stations in Hawai'i and contemporaneous patterns in large-scale atmospheric fields across the Pacific region and vertical profiles over the islands, and use those statistical relationships to assess whether model simulations of future climate suggest changes in the frequency of extreme high rainfall events in Hawai'i.
3. Establish statistical relationships between occurrences of periods of extreme low rainfall at selected raingage stations in Hawai'i and contemporaneous patterns in large-scale atmospheric fields across the Pacific region and vertical profiles over the islands, and use those statistical relationships to assess whether model simulations of future climate suggest changes in the frequency of extreme low rainfall events in Hawai'i.

Methods

Trends in Rainfall and Changes in Spatial Patterns of Rainfall: As part of current projects to compile high resolution climate data sets and to revise the Rainfall Atlas of Hawai'i, we are developing serially-complete data sets for a large number of raingage stations in Hawai'i. After completing the gap-filling process and after testing the reliability of the gap-filled data, we will develop rainfall anomaly maps for each year and each decade of record. Spatial averages will be computed for each island and for regions (based on exposure). These spatial averages will provide the first ever comprehensive time series of rainfall in Hawai'i, from which trends and pattern shifts can be determined with confidence.

Extreme Wet Events: Using the daily rainfall record of selected stations, the days with rainfall totals in the upper decile will be selected. Using the NCEP reanalysis data set, composites will be compiled of horizontal pressure, wind, temperature, and humidity fields for the North Pacific region for the days with extreme high rainfall at each station and for 6-month summer and winter seasons. Vertical profiles of selected variables over the islands will also be calculated. For each composite horizontal pattern and vertical profile, we will test whether more than one discrete pattern regularly occurs for the high rainfall days. Once all the important patterns for a given field of profile are identified, the corresponding mean fields will be subtracted from each composite, to derive the anomaly fields associated with intense rainfall. We will then examine the fields produced by selected global climate models for a future with enhanced greenhouse effect to determine whether patterns associated with extreme high rainfall are likely to become more or less frequent.

Extreme Dry Events: The monthly rainfall record of selected station will be used to identify periods of low rainfall. A standardized rainfall index will be produced, from which the driest periods of different durations will be identified for each station and for each season. Again, the NCEP reanalysis data set will be used to composite various

horizontal fields and vertical profiles to determine the patterns associated with extreme dry conditions. As with the analysis of extreme high rainfall, global climate model output will be examined to determine whether patterns associated with extreme dry periods are likely to become more or less frequent due to the effects of global warming.

Relation to Ongoing Research

The proposed study will complement two current projects related to Hawaiian rainfall: (1) Revision of the Rainfall Atlas of Hawai'i. and (2) High Resolution Climate Data Sets for Climate Diagnostics and Climate Change Detection in Hawai'i. The proposed work will build on these two projects and increase the scope of work to include analysis of historical rainfall trends and projection of changes in extreme rainfall in Hawai'i. The Rainfall Atlas project will provide a spatial framework for the proposed analysis, by using multiple independent predictors of the rainfall pattern and cutting-edge data fusion technology to produce the most accurate and detailed map of mean monthly and annual rainfall for the State. The High Resolution Climate Data Sets project is providing the completely gap-filled rainfall data base, essential for the proposed study.

Budget Request

The exact amount of available funding is not precisely known at this time. However, we are anticipating new funding of approximately $131,000. After administrative costs at various levels, we expect the available direct costs to be around $100,000. We will propose to use those funds to support the participation of the Principal Investigator—Thomas Giambelluca (Geography, UH Mānoa), Co-Principal Investigators—Henry Diaz (University of Colorado) and Oliver Timm (IPRC, UH Mānoa), and a graduate assistant, and provide travel support for Dr. Diaz to visit Hawai'i for collaboration on the project.

References Cited

Chu, P.-S. and H. Chen. 2005. Interannual and interdecadal rainfall variations in the Hawaiian Islands. *Journal of Climate* 18: 4796–4813.

Giambelluca, T.W., Diaz, H.F., and Luke, M.S.A. 2008. Secular temperature changes in Hawai'i. *Geophysical Research Letters* 35, L12702, doi:10.1029/2008GL034377.

Timm, O. and Diaz, H.F. 2009. Synoptic-statistical approach to regional downscaling of IPCC twenty-first-century climate projections: seasonal rainfall over the Hawaiian Islands. *Journal of Climate* 22: 4261-4280, doi:10.1175/2009JCLI2833.1.